

# Activity report of ILD-TPC Asia group

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The purpose of ILD-TPC Asia group is realization of high precision Time Projection Chamber (TPC) with Gas Electron Multiplier (GEM) as a central tracker in International Linear Collider (ILC). We have been studying the many R&D items to build the real detector as a member of LCTPC collaboration. This paper describes the our efforts for realization of the ILD-TPC, the result of test beam using large prototype TPC, local field distortion, positive ion effects and gate devices, and cooling electronics which are key items to build ILD-TPC.

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## I. INTRODUCTION

The International Linear Collider (ILC) has possibility of the discovery of the beyond standard model [1]. ILC is proposed to build two detector systems, ILD [2] and SiD. The ILD concept is optimized for particle flow analysis(PFA) [3] aiming at measuring every particle in an event with higher precision. PFA requires the combination of three detectors, trackers, electromagnetic calorimeters (ECAL), and hadronic calorimeters (HCAL) to reconstruct the every particles, even inside jets. The requirement of the central tracker of ILC are; (1) momentum resolution is less than  $2 \times 10^{-5} \text{ GeV}^{-1}$  and (2) good 2-hit resolution ability.

The central tracker of the ILD is a Time Projection Chamber (TPC) which measures the charged track with a large number of three-dimensional  $(r, \phi, z)$  space points and has a minimum amount of material budget. The size of ILD-TPC is 329 mm for inner radius, 1808 mm for outer radius, and  $2350 \times 2$  mm (divides two parts) for  $z$  direction [1]. And ILD-TPC is inside of magnet with 3.5 T and has 224 measuring layers. Under these conditions, ILD-TPC has to have the spatial resolution with less than  $100 \mu\text{m}$  and 2-hit resolution with less than 2 mm to satisfy the above requirement (1) and (2). The traditional TPC has a read out devices by multi-wire proportional chambers (MWPC). But under the ILD condition which is the magnetic field of  $B = 3.5 \text{ T}$ , the strong  $E \times B$  effect leads to the deterioration of the spatial resolution. Therefore other read out devices are needed for the TPC read out system.

LCTPC collaboration [4] formed to join the international efforts to develop ILD-TPC. The group from Asia, Europe, and America are involved in this research. LCTPC collaboration has investigated the use of Micro Pattern Gaseous Detector (MPGD) as the read out system. The characteristic of MPGD is the gas amplification in the small pitch of order 10 -  $100 \mu\text{m}$ . This improves the spatial resolution and reduce of  $E \times B$  effect.

ILD-TPC Asia group [5] is consist of Japan (KEK, Kinki U., Saga U., Tokyo U.of A&T, Kogakuin U., Hiroshima U., NiAS), China (Tsinghua U.), and Philippines(Mindanao U.) which join LCTPC collaboration. The aims of ILD-TPC Asia group is development of TPC with GEM (Gas Electron Multiplier) [6] appropriate for ILD-TPC. GEM is a foil made of a metal-insulator-metal sandwich and has many microscopic holes with the microscopic pitch. GEM used by our group consists of a  $5 \mu\text{m}$  copper layer on both side of a  $100 \mu\text{m}$  LCP layer. And it has a keystone like shape of dimension  $17 \times 22 \text{ cm}^2$ . The holes are drilled by the

laser with a diameter of  $70\ \mu\text{m}$  and make the hexagonal pattern of a pitch of  $140\ \mu\text{m}$ . When the electron released in the gas pass through the GEM holes, the electric potential difference between the upper and lower copper side amplifies the electrons. The double GEM layer system has been introduced to obtain the sufficient electron amplification.

## II. TEST BEAM AND ANALYTIC FORMULA

LCTPC collaboration has built the TPC large prototype (LP) system in the DESY II test beam area T24/1 [7]. The purpose of this LP is pushing forward the substantial study of MPGD TPC in the situation that is near to an actual conditions. FIG. 1 is a picture of LP system. LP consists of a large cylindrical field cage with a modular end plate, allowing

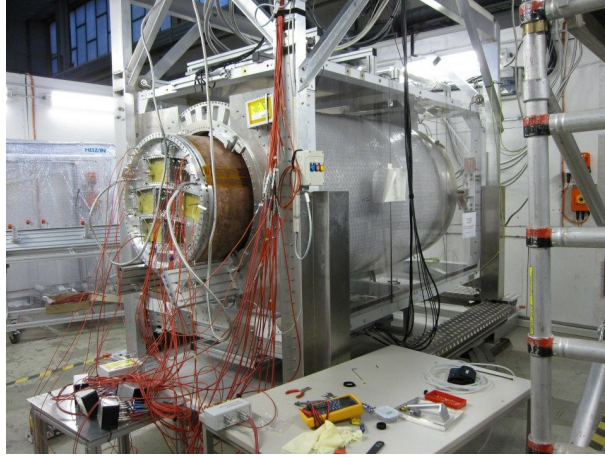


FIG. 1. TPC LP system in the DESY II test beam area T24/1

up to 7 detector modules to be mounted. LP is inserted in the PCMAG superconducting magnet of  $B = 1\text{T}$ . The size of the field cage is  $72\text{ cm} \times 61\text{ cm}$ . We built 3 double GEM layer modules and have taken four times of the test beam with LP from 2009 to 2012 using  $p = 5\text{ GeV}/c$  electron beam. This section explains the result of 2010 and 2012 test beam.

The 2010 test beam didn't have enough data because the discharge which was occurred on GEM damaged the read out electronics. And wrong voltage setting of the field shaper caused a large distortion around the module boundary (See FIG. 6). Based on failure of 2010 test beam, there were some improvement for 2012 test beam, (1) optimization of the field shaper's voltage setting, (2) increase the partitions (2 to 4) of GEM electrode to protect the read out electronics by discharge, (3) add protection circuit to read out electronics. These

improvement led to get the many various data (with and without magnetic field, scanning  $x$ -direction, scanning  $\theta$  and  $\phi$  direction, etc) on 2012 test beam.

FIG. 2 shows the dependence of the drift length on the transverse point resolution. In

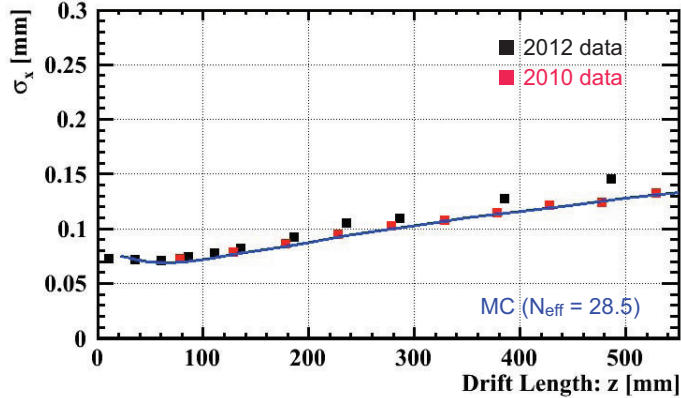


FIG. 2. Dependence of the drift length on the transverse spatial resolution

this figure, there is a different behavior between 2010 and 2012 data. The resolution on 2012 data turns worse as the drift length become long rather than 2010 data. We tried to find the cause of this deterioration, but it can't be explained by gain uniformity, discharge effect, cross talk, threshold effect, etc [8]. This figure also shows that 2012 data has some data points nearer than 10 cm and these data seems consistent with 2010 data within 10 cm. We conclude the deterioration of the resolution is caused by a charge loss somehow because the influence of the charge loss affects longer drift length. The charge loss may be happened by gas leak or not correct value of the oxygen monitor. 2010 and 2012 data are compared with Monte Carlo simulation by our analytic formula [9] which is based on 2010 data ( $N_{\text{eff}} = 28.5$ ). FIG. 3 shows the comparison result. The figure shows 2010 data consists with the simulation without charge loss and 2012 data consists with the simulation with -5%/cm charge loss. And the simulation shows the influence of charge loss is small at the short drift length. The charge loss by the really lost seed electron can explain the change for the deterioration of the transverse resolution on 2012 data. As the conclusion, 2012 data is consistent with 2010 data taking account into the real charge loss.

In order to estimate the performance of real ILD-TPC with the result of the test beam data, it is important to establish the principle formula for the spatial resolution. Our group has developed a new analytic formula which is applicable to tilted tracks [9]. The special resolution consists of four components, [A] systematics due to finite pad read out,

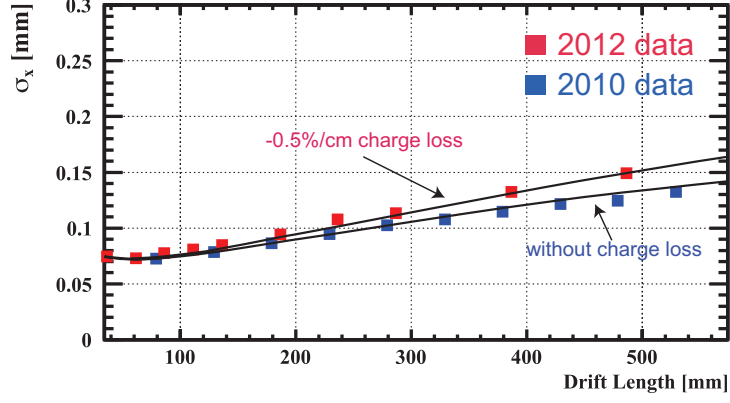


FIG. 3. Comparison test beam results and simulation

[B] diffusion effect, [C] electron noise effect, and [D] primary cluster fluctuation. Term [D] makes effort to resolution of inclined track. By examining physical meanings of each term of the formula, we can identify what factor mainly contributes to the spatial resolution, which help us find a way to improve the spatial resolution. This formula attempts to 2010 data. FIG. 4 shows the result of comparison 2010 data and the formula. The line of the

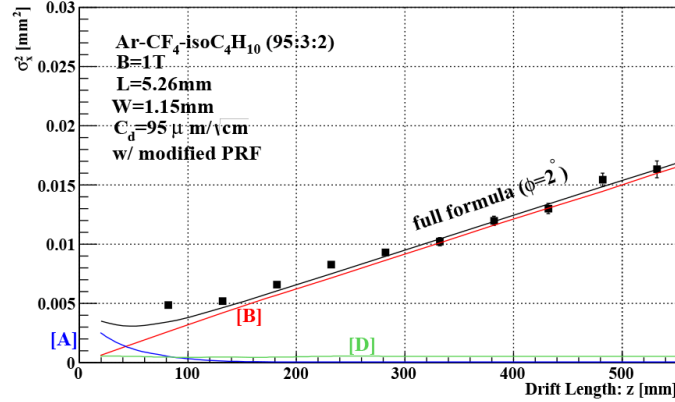


FIG. 4. Spatial resolution as a function of drift length. The plot shows  $\sigma_s^2$  of the 2010 data together with analytic formula. Black circle is 2010 data. [A] is the systematic term, [B] is the diffusion term and [D] is the cluster term.

formula is not include the term [C] assumed to be negligible. FIG. 4 shows the formula to

be consistent with 2010 data and the formula shows the track to be inclined  $\phi = 2^\circ$ . Using this formula and the basic parameter for the spatial resolution such as,  $C_d$ ,  $PRF$ ,  $N_{\text{eff}}$  and  $\hat{N}_{\text{eff}}$  obtained by the 2010 data, we can estimate the performance of the ILD-TPC. FIG. 5 shows the expect performance of the spatial resolution on ILD-TPC by 2010 test beam results. Case (a) in FIG. 5 is estimated by Magboltz for  $B = 3.5$  T with the same

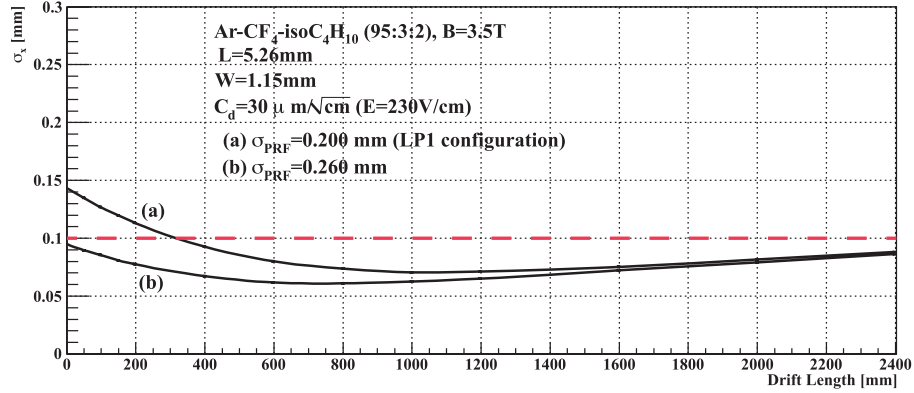


FIG. 5. The expect performance of the spatial resolution for ILD-TPC by 2010 test beam. (a) is estimated by Magboltz for  $B=3.5$  T with the same configuration as our test beam. (b) shows a virtual case of  $\sigma_{PRF} = 0.260$  mm.

configuration as our test beam. Case (b) in FIG. 5 is not based on any real detector, but it can be realized if we take larger gap between GEMs and the stronger electric field in the gap. The expect performance of the spatial resolution based on our test beam result can be expected to satisfy the requirement ( $\sigma \leq 100 \mu m$ ) of ILD-TPC for almost drift region.

### III. LOCAL FIELD DISTORTION

As mentioned in the previous section, 2010 test beam data has a big distortion on all modules in FIG. 6 (a). The distortion has occurred around the module boundary. The cause of distortion is wrong setting of HV on field shaper. Since the distortion makes the worse of the spatial resolution, the decrease of the distortion is important. In 2012 test beam, GEM module is increased the partitions of electrode (4 partitions) and optimized HV of field shaper to suppress the distortion. FIG. 6 (b) shows there is a smaller distortion on the module boundary than 2010, but the small distortion is appeared at the electrode

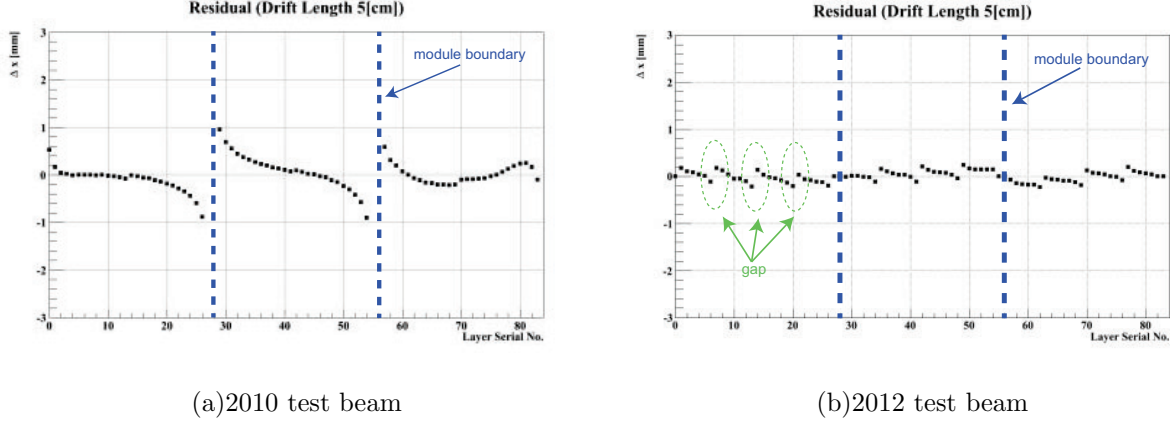


FIG. 6. The residual distribution of three modules

boundary in GEM. The size of electrode gap of 2012 GEM module is 1 mm but the size of 2010 is 200  $\mu\text{m}$ . Our simulation study found this wide gap has disturbed the field uniformity around the gap. The good field uniformity needs more narrow gap. We improved the new GEM module to suppress the distortion for next test beam. The improved GEM has the boundary gaps on the front side only and changes gap size to 500  $\mu\text{m}$  from 1 mm. Since it is important to measure the distortion by other method before the test beam, we make the UV laser system to measure it. The test plans with UV laser system measure the distortion of improved GEM and compare to simulation and measure the distortion of GEM with wire gate.

#### IV. EFFECTS OF POSITIVE ION AND GATE DEVICES

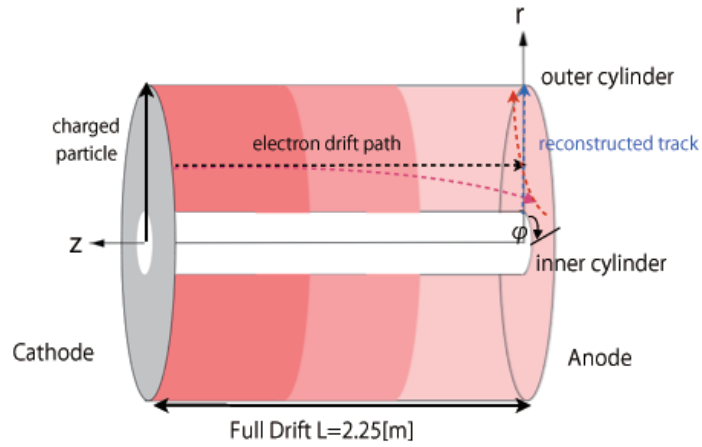
Positive ion effect is one of main problems of TPC to get the excellent spatial resolution. Positive ion generated by ionization and gas amplification move to the cathode and disturb the field uniformity in the drift region. TPC with MWPC has to be equipped the gate device because all ions goes back. Since there are a lot of ions in TPC at the ILC, we have investigated the ion effect on TPC with MPGD(GEM) [10].

The method of the estimation of the ion effect is,

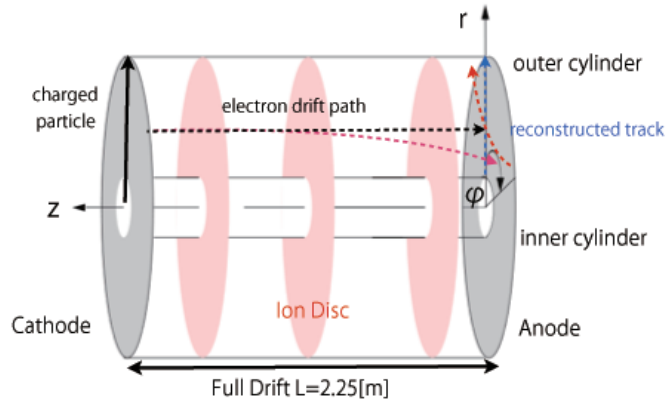
1. make the ion density distribution with the signal and background simulation
2. estimate the field distortion by solving the Poisson equation with proper boundary conditions

3. evaluate the distortion of drift electron trajectory from the field distortion by the Langevin equation

There are two type of ion, the primary ion and the secondary ion, which have different origin and effects on the positive ion effect. The primary ion comes from the ionization by the charged particle and moves to the cathode. The frequency of a beam train in ILC is 5 Hz [1] and the drift region existed the three primary ion cylinder by three a beam train at same time. FIG. 7 (a) illustrates the primary ion effect on ILD-TPC. The secondary



(a)primary ion (associated with track)



(b)secondary ion (associated with GEM)

FIG. 7. Positive ion effect on ILD-TPC

ion comes from the gas amplification and the secondary ion density is calculated with (the number of primary ion)  $\times$  (ratio of the entering of the primary ion to gas amplification)  $\times$



(gas amplification factor). In our estimation, the density of the secondary ion is about 2 to 9 times bigger than the density of the primary ion. The distribution of the secondary ion is different from the primary ion as FIG. 7 (b). The secondary ion by a beam train in ILC forms a disk of thickness 4 mm and moves to the cathode. The drift region has three ion disk at same time on ILD-TPC. Using the above simulation results, the distortion of the track is estimated for the both case. TABLE I shows the distortion of the reconstructed track by the positive ion. The primary ion doesn't affect the distortion of the track. And

TABLE I. Distortion of track by positive ion

	<b>without</b> gating device	<b>with</b> gating device
Primary ion	8.5 $\mu\text{m}$	8.5 $\mu\text{m}$
Secondary ion	60 $\mu\text{m}$	0.01 $\mu\text{m}$
sum	70 $\mu\text{m}$	8.5 $\mu\text{m}$

the gating device can't suppress the distortion by the primary ion. The secondary ion make much effort to the distortion. The gating device can suppress to the distortion. Therefore ILD-TPC has to need to equip the gating device which suppress to the distortion by the secondary ion.

ILD-TPC requires the performance of the ion gate devices to (1) ion feedback must be smaller less than  $10^{-3}$ , (2) gate can open for 1 msec and close following 199 msec, (3) drift of ion can be less than 1 cm. There are 3 candidates of the gate devices, wire, GEM, and micromesh, suitable for ILD-TPC.

The wire gate is used TPC with MWPC. The effect of an open wire gate on the electron trajectories should be negligible, even in a high magnetic field. Since the existing wires deteriorate electric field around a wire, some  $E \times B$  effect may happen at around a wire. Building a wire gate independently from MPGD read out modules would require extra structure, and would be difficult to achieve without introducing problematic dead region. ILD-TPC also requires a wire gate to be included within the MPGD read out modules. There are two different configurations that can be considered, transverse wires and radial wires. The radial wire system is preferable for the small modules of ILD-TPC. The support structure would be mainly transverse to the tracks, so that the dead region would not interfere the tracking coverage. Our group made a radial wire gate module and tested it

with Fe55. FIG. 8 (a) is picture of our wire gate module. A wire of  $30\ \mu\text{m}$  in diameter is

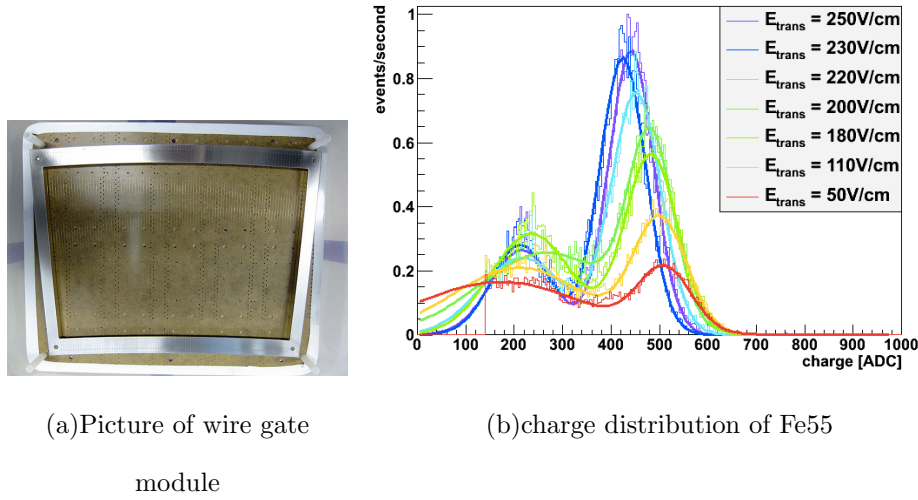


FIG. 8. wire gate module and it's charge distribution

put on this gate every 2 mm and spot welded on stainless steel frame (up and down). This only applies a single potential regime for the closed gate configuration. Using this gate, we measured the Fe55 spectra for different HV configuration with fixed drift field (230 V/cm). FIG. 8 (b) is the charge distribution of Fe55. This figure shows the decrease of the transfer (the region between gate and GEM) field lead to the decrease of the transmission efficiency.

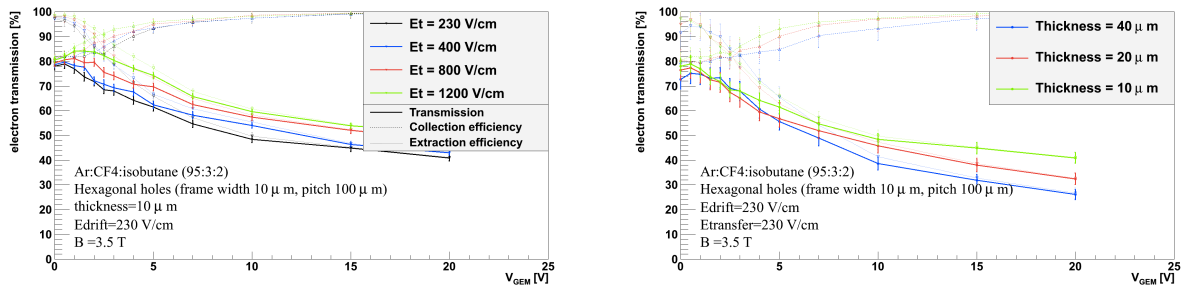
GEM gate is a good candidate for TPC with GEM because it is almost same frame and can be stacked on GEM module. F.Sauli suggested to use GEM as the ion gate devices in TPC [11]. The key issue of GEM gate is the electron transmission. We made a thin GEM gate of  $14\ \mu\text{m}$  thick with  $90\ \mu\text{m}$  holes and  $140\ \mu\text{m}$  pitch and measured the electron transparency [12]. This GEM offers 37% geometrical aperture. This measurement has done with a 1 T magnetic field and T2K gas ( $\text{Ar} : \text{CF}_4 : \text{iC}_4\text{H}_{10} = 95 : 3 : 2$ ). This measurement shows a maximum transparency to be below 40% around 10 V. The simulation can describe this results and the increase of aperture size has been a key parameter in a magnetic field. Getting the satisfied transparency, we simulate a GEM geometry with a maximized aperture as a hexagonal honeycombed structure in FIG. 9 [12]. This structure offers an 81 % aperture, but it is difficult to build this structure with thin devices. As for the simulation, the electric field was calculated in ANSYS on one sector of the GEM, using symmetric boundaries and the Garfield++ simulation uses these symmetries to extrapolate the field to the whole space.

We measured the simulated electron transmission efficiency for different transfer field and



FIG. 9. GEM geometry simulated. Only one sector is used for field calculations, using symmetries.

different thickness of the GEM [12]. FIG. 10 shows the influence of these parameters is as expected with 3.5T magnetic field. These figures show the maximum transmission efficiency



(a) Electron transmission for different transfer field (b) Electron transmission for different GEM thickness

FIG. 10. Results of simulation with large aperture GEM in a 3.5T magnetic field.

is reached above 70% in the special conditions (very large aperture, very thin structure, a higher transfer field). A transmission efficiency close to the geometrical aperture of the GEM can always be achieved for low voltage. Due to the large  $\omega\tau$  of T2K gas in the large magnetic field, the transfer field and thickness have little influence on the transparency. We will challenge to product a GEM gate with suitable mechanical properties of ILD-TPC. This might be possible with large holes and relatively thick GEMs.

## V. COOLING FOR ELECTRONICS

ILD-TPC group is investigating to introduce the 2-phase CO<sub>2</sub> cooling system as the cooling for the read out electronics. The advantages of the 2-phase CO<sub>2</sub> cooling are, (1) the latent heat of the liquid CO<sub>2</sub> is very big with 300 J/g, (2) coverage of cooling is down to -40 degree from room temperature, (3) using the latent heat for cooling can suppress a raise

in cooling temperature by a temperature rise of the refrigerant, (4) using of a high-pressure refrigerant and small liquid viscosity can use thin pipe for the cooling system and deduct the material budget, (5) it is free from worry about the short circuit of the detector even if there is a leak of the refrigerant.

KEK CO<sub>2</sub> group [13] took a demonstration experiment of simplified 2-phase CO<sub>2</sub> cooling system in 2011 and 2012 and confirmed the ability of cooling power. ILD-TPC group made the small 2-phase CO<sub>2</sub> cooling system with 2-phase CO<sub>2</sub> circulation pump in cooperation with NIKHEF in 2012. This system put on ILD-TPC large prototype test facility in DESY and use the heat control for electronics. We also study of cooling system for S-ALIRO16 read out electronics with thermal simulation.

## VI. SUMMARY AND FUTURE PLAN

ILD-TPC Asia group has been studying the high precision TPC with GEM as a central tracker of ILC-ILD as a member of ILD-TPC collaboration. We took the test beam using the large prototype TPC in DESY at 2010 and 2012. The both results are consistent with each other taking into account of the real charge loss at 2012. Analytic formula for TPC with GEM has been evolved and explains the results of test beam data. Using the analytic formula, the prospective performance estimated from the test beam data can be expected to satisfy ILD-TPC performance. We will take the test beam with  $B = 3.5$  T magnet with a new read out electronics and 2-phase CO<sub>2</sub> cooling system.

The GEM used by test beam of 2010 and 2012 had occurred the distortion problem. Since the distortion makes the spatial resolution to be worse, we design the new GEM module which suppress the distortion. And our laser test system can measure it before the test beam.

Development of the gate device is a key issue for ILD-TPC. The requirement of spatial resolution requires to suppress the secondary ion effect and to have the gate device. The GEM gate is a strong candidate for ILD-TPC with GEM. The simulation study of GEM gate shows the geometrical aperture ( $> 70\%$ ) is the key parameter in high B field. The main problem for GEM gate is building such large aperture GEM. We will make a large aperture GEM gate and measure the electron transparency.

The study of 2-phase CO<sub>2</sub> cooling system has just started. We build the colling system

to check the cooling ability and this system will be used test beam at DESY. The design of cooling system is an important R&D items. We are studying the cooling system for the electronics in cooperation with ILD-TPC collaboration.

## ACKNOWLEDGMENTS

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